An Integrated IoT Architecture for Smart Metering

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***Abstract*— Advanced Metering Infrastructures (AMI) are systems that measure, collect, analyse utilities distribution and consumption, and communicate with metering devices either on a schedule or on request. AMI are becoming a vital part of utilities distribution network and allow the development of Smart Cities. In this paper we propose an integrated Internet of Things (IoT) architecture for smart meter networks to be deployed in smart cities. It is shown the communication protocol, the data format, the data gathering procedure and the decision system based on big data treatment. The architecture includes electricity, water and gas smart meters. Real measurements will show the benefits of the proposed IoT architecture for both the customers and the utilities.**

***Index Terms*—Smart Metering, Network Architecture, IoT, Big Data, Smart City**

1. INTRODUCTION

The integration of intelligent measuring devices in a city using Internet of Things (IoT) allows collecting all the data necessary to become a smart City. They are a fundamental part for keeping the city connected and informed, and ensure that each subsystem performs its function. The integration of information technology helps to control the subsystems that form the smart city. The installation of cutting-edge technologies regarding measurement, communications and systems, network automation and distributed generation, among others, facilitates the development of the city. The goal is to achieve a better management of the electric energy, water and gas providing networks and an efficient balance between demand and consumption. A key technological element in this context is the smart meter, which can be a thing inside IoT.

A smart metering system allows the water, electric and gas utilities a continuous consumption reading and recording in time intervals or, at least, daily reporting, monitoring and billing. Smart meters enable two-way real-time communication between the meter and the utility central system. This allows the utility to gather interval data, time-based demand data, outage management, service interruption, service restoration, quality of service monitoring, distribution network analysis, distribution planning, peak demand, demand reduction, customer billing and work management. In recent years, the advances in Information and Communication Technologies sector have permitted the evolution from the simplest Automated Meter Reading systems to Advanced Meter Infrastructures (AMI). These allow demand-response management, enabling customers to make informed decisions and consumption prediction. AMI are becoming a vital part of the water, electric and gas utilities distribution networks [1]. Regardless of the technology used, it is essential for surveillance, and to monitor and control the distribution and consumption levels. A key element in AMI is the communication between the meters and the utility servers. Several communication technologies have been proposed and implemented. In most cases, utilities are installing a specific communication infrastructure for each smart metering technology which implies that:

- In a certain area only meters using the technology selected for that area can be installed
- Sometimes they cannot install the best solution because of the communication infrastructure
- External devices are needed to permit the communication, which worsen the city landscape

- When a new meter is installed, the network must be modified, sometimes some devices must be replaced

- It is necessary to train the personnel in charge of the metering maintenance

Smart metering for electric power has advanced significantly in the last few years [2]. It has brought the appearance of several communication standards for smart metering the power system, but most of them cannot be applied to the water or gas distribution systems. Moreover, there is a lack of a standard for the data and the alarms that are sent or displayed by the metering devices.

In this paper, we propose an integrated IoT architecture for electricity, water and gas smart metering, which benefits both the customers and the utilities. The rest of paper is structured as follows. Section 2 describes the main features of the smart meters technology in our proposed architecture. The proposed integrated IoT communication architecture is described in Section 3. Section 4 reviews the current communication protocols that can be used in our IoT architecture. Section 5 shows the intelligent systems used in the Big Data to take decisions and provide information to the utility. Section 6 lists the benefits for both the utilities and customers and provides some examples of real cases in order to show the power of the proposed system. Finally the conclusions are drawn in Section 7.

2. SMART METERS

A smart meter is a digital electronic device that collects information on electricity, water or gas use and sends it securely to the utility. These counters provide insight into consumption in real-time to the utility and, in some cases, to the end user. In addition, these data allow understanding the spending habits, improving the network efficiency and contributing to electricity, water or gas saving. Thanks to the smart meters, the consumption data can be managed and any impact on the network can be monitored in real-time. For this reason, it is important to emphasize some functional aspects related to these devices. On one hand, the battery lifetime of the meters limits the quantity and frequency of sending data. Some power saving and energy optimization techniques should be applied [3]. On the other hand, high data readings frequency opens a new spectrum of possibilities for the understanding the electricity/water/gas demand network and for the services management [4]. Moreover, the location of meters often limits the signal transmission meaning the lack of 100% real-time data. Sometimes, there is a gap of hours or even days from the moment when the measurements are gathered from the meters and the moment when the information reaches the utility server. Real-time data from meters would allow synchronisation with District Metering Areas meters and consequently the possibility of making balances. This fact would dramatically reduce the response time in front of leaks, fraud, etc. Several smart meters can be bought in the market since little time ago, and IoT has appeared to be the most feasible solution to communicate with them. Figure 1 provides a list of features and the indicators needed in the smart meters regarding to the electric energy, communications, data, real-time alarms, and cost and maintenance.

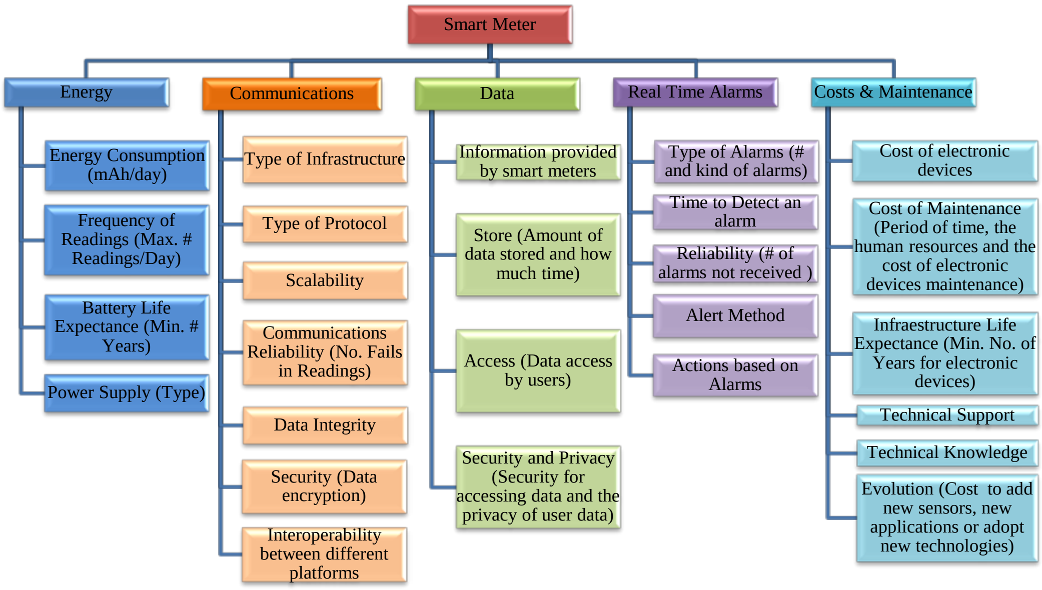

Figure 1. Features of the Smart Meters

3. ARCHITECTURE AND COMUNICATION PROTOCOLS

AMI systems include sensors [5], hardware, software, communications, consumption displays and controllers, customer systems, data mining software, meter data management software and business systems. They provide two-way communications with the meter, allowing sending commands from the utility to the smart meter for multiple purposes, including monitor real-time values and change the frequency of readings among others. The network between the smart meters and the utility centre allows collection and distribution of information to customers, suppliers, utility companies, and service providers.

A layered architecture allows us to classify all components and interfaces into different categories according to their features and purposes. Our proposed architecture uses three layers (see Figure 2). Smart meters, network devices and communication protocols to allow smart metering through Internet are included in Layer 1. Devices in charge of receiving data at the utility side form layer 2. Layer 3 includes artificial intelligent systems in big data in order to provide information to the decision systems and the billing systems.

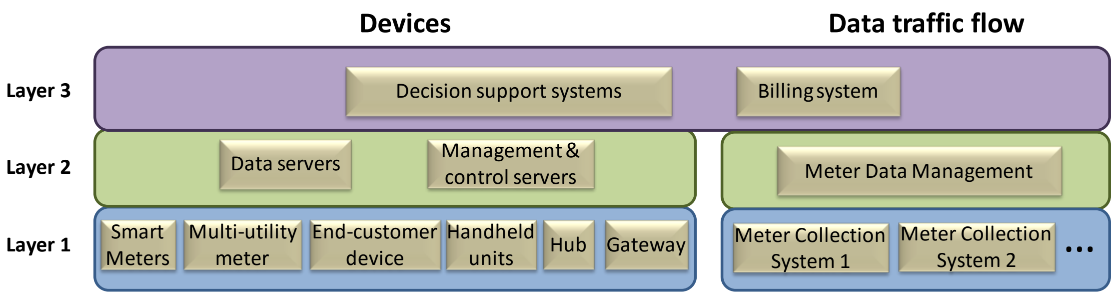

Figure 2. Proposed architecture

The proposed communication architecture includes any type of local/remote communication. Each specific case has different appropriate communication technology, which is dependent to the environment conditions and multi-criteria decision techniques. Quantitative and qualitative variables are taken into account to choose the best communication technology. The main ones are the smart meters location and distribution, the distances meter-meter and meter-hub, the urban context and restrictions, the communication costs and the scalability.

Existing proprietary smart meter communication protocols are only appropriate for deployments with few smart meters or for a specific geographic context. Meters from different manufacturers have different features. Therefore a certain meter or solution may be or may not be the best option depending on what is the utility looking for. Each smart meter has its benefits and drawbacks. There is no model with enough technical features to cover completely all possibilities in a real environment. The lack of a common communication standard makes impossible the interoperability with smart meters from other manufacturers. With this purpose, OMS-Group [6] proposed an open standard communication protocol stack, called Open Meter project that specifies the key elements of the architecture, which was not manufacturer dependent.

Since the amount of communication technologies is wide, the proposed communication IoT architecture includes a wide variety of communication protocols, while it allows many ways of connecting the smart meters with the utility centre through Internet. It is very flexible and includes local and remote communications. In order to carry out a detailed protocols analysis, 5 main zones are distinguished (see figure 3):

- Direct connection: between handheld units/end-customer devices to smart meters.
- Meter access network: the communication network formed by the smart meters in a single place.
- Meter-Gateway Network: the network that allows scalability (using hubs). It is generally ended by a gateway.
- Telecommunications service provider network: it allows connecting the gateways with the utility centres through Internet.
- New cellular technology: it allows a connection between the smart meter and the utility centre through Internet using last cellular technology such as D2D or M2M [7].

Leaving aside the communication protocol for direct connection between the handheld unit and the smart meter, and between the end customer device and the smart meter, where there are well stablished standardized protocols and some proprietary protocols, the communication protocols that are studied in detail are included in last 3 zones.

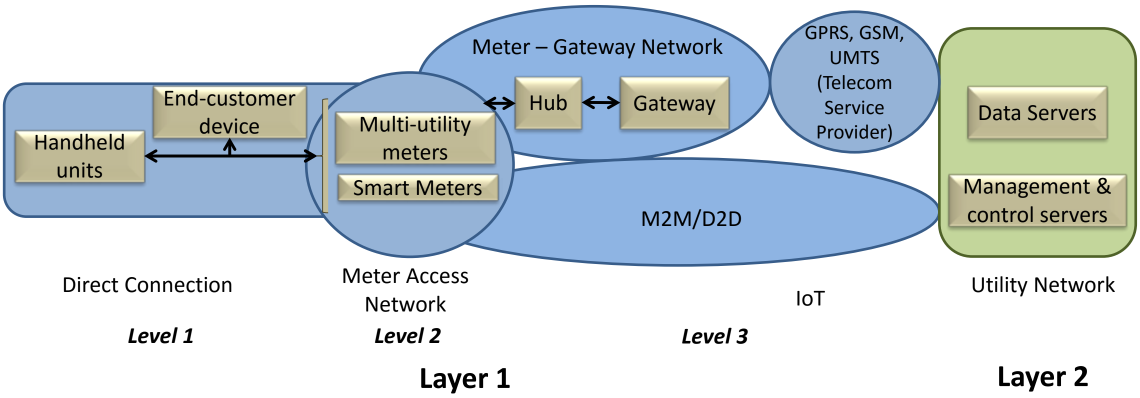

Figure 3. Communication technologies in the proposed architecture.

Communication technologies for collecting and transporting data can be wired, wireless mobile, wireless fixed network or a combination of them. Data, message frequency and alarms are included in application layer protocols. The choice of the technology depends on multiple factors such as the challenges the utilities face, the configuration of the deployment field, benefits using the data and the information, working process inside the utility, maturity of the knowledge, and economical aspect.

The amount of protocols that can be used in each zone is high. Moreover, it is constantly increasing. Some of them are proprietary and developed exclusively for water metering and others are well known communication standards. Furthermore, advances in smart metering for electrical power have proposed new communication protocols which do not use the power line to transmit the information, so they can be also used in water and gas metering [8][9]. We classify the protocols intro several categories.

- First category includes the standardized and open meter access protocols. The main ones are EN 13757 (M-bus) [10], which can alternatively be used with DLMS/COSEM, ANSI C12.18, ANSI C12.21, CzBus, Wavenis, EverBlu, Serial Coded Tele-Metering (SCTM) protocol (IEC 60870-5-102), KNX, LonTalk, LonWorks, IEC 62056, IEC 62056-21 (also known as IEC 1107).

- The second category includes general purpose standardized communication protocols. There are network topologies where data are sent wirelessly to a nearby hub or gateway directly or to a set of sub-trees with a root node. In other cases there is a wireless ad hoc network or a wireless mesh network with a gateway. They are IEEE 802.15.1 (Bluetooth), IEEE 802.15.4 [11], 6LoWPAN, and IEEE 802.11.
- The third category includes some well stablished proprietary systems. E.g. Plextek, which is based on a proprietary Ultra Narrow Band technology, includes a proprietary digital signal processing techniques and an additional frequency hopping. It is a short-range low-cost radio solution, which operates in the 868 MHz or 915 MHz ISM frequency bands. It uses a point-to-multipoint architecture allowing handling a large numbers of devices (typically 5,000 - 10,000) per hub, and has modest data rate requirements. Hubs have a 2 – 20 km cell radius.

When we classify existing technologies into wired and wireless, the most commonly used wired technologies include Public Switched Telephone Network (PSTN), the Asymmetric Digital Subscriber Line (ADSL) and the Fiber to the Building or Fiber to the Home (FTTx). In the wireless group, we can find a wide range of solutions: Terrestrial Trunked Radio (TETRA), ERMES and ReFLEX, 2G (Global System for Mobile communications, GSM, General Packet Radio Service, GPRS, and Enhanced GPRS, EGPRS), 3G (Universal Mobile Telecommunications System, UMTS, High Speed Downlink Packet Access, HSPA and HSPA+), IEEE 802.16, Long Term Evolution (LTE), and Mobile satellite communication.

The appearance of these zones has brought us to define different types of interfaces to connect devices from different zones. In Figure 4 we differentiate 4 types of interfaces.

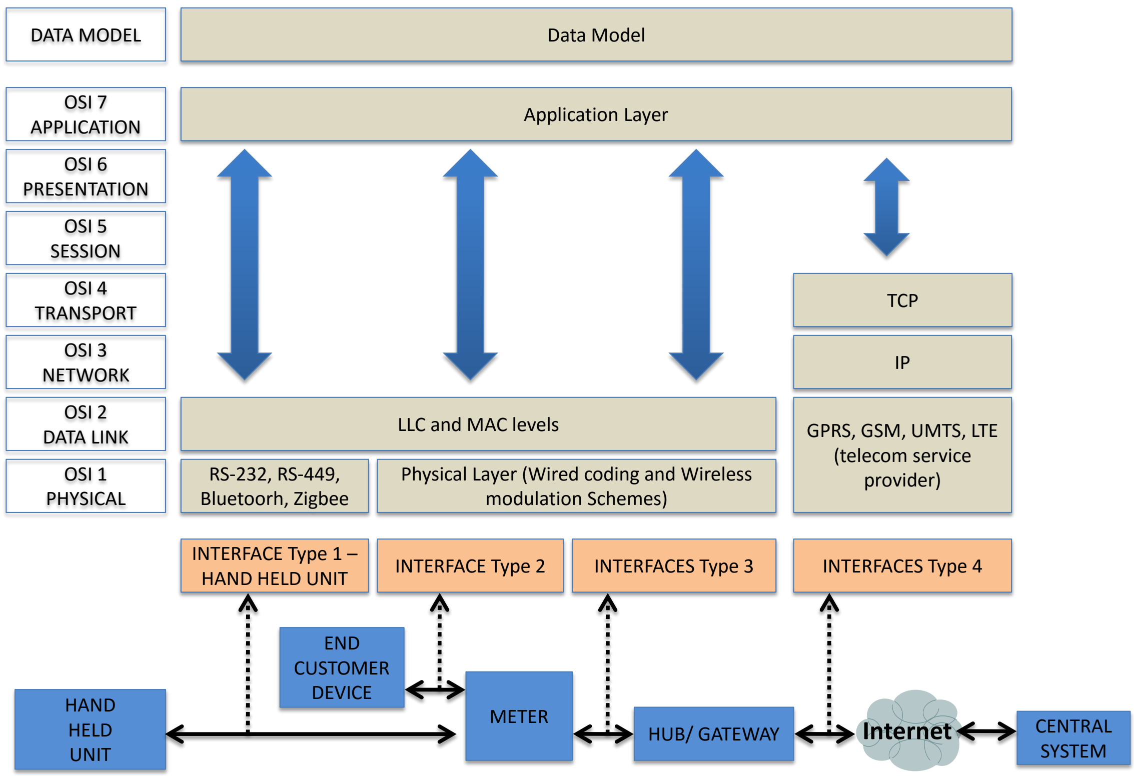

Figure 4. Communication protocol stack.

4. BIG DATA

Once the data has been gathered, it is very important to use the most powerful techniques to extract the most useful data [12]. In this section we describe some of the current systems to facilitate the process of treating high volume of data. Then, we show our proposal to use the smart meters inside IoT.

Every Big Data system needs a processing infrastructure based on cluster computing, that has a distributed file system, where the database system is installed, allowing a concurrent programming model. One of the first systems was proposed by Google in 2004. It was based on Google File System. It had Big Table for the data bases and MapReduce as the parallel execution model. Inspired on the Google solution, Hadoop appeared which offers an open source solution with an Apache license. Since 2012, there is another open source alternative, Apache Spark [13]. Apache Spark doesn't define a cluster manager and a distributed storage system. It allows the use of many different components (for example, Hadoop ecosystem can accommodate it). It uses Spark SQL as a database system. For the parallel execution, it can use the abstraction distributed dataset (RDD), more versatile and fast than MapReduce. Hadoop and Spark are the most used Big Data processing frameworks. We have chosen Spark, especially because it integrates MLib, Spark's machine learning library.

Data collected from electricity, water and gas smart meters using IoT can be used for many purposes. Those purposes drive us on how the data should be structured and prepared. Next goals are the most demanded by the utilities.

- Prediction of future consumption: The system should be capable of predicting the future consumption for each user or group of users. This information is needed to adjust the distribution network for the future use. A field where this can have a clear significance is in the power demand prediction in the smart grids [14].

- Detection of incidents: The system should be able to provide alerts of some anomalies. It should be able to warn the customers in case of an incident like water leaks, and should also be able to detect anomalies like fraud by manipulation of the meters.

- Characterization of the kind of customer: To know the type of customer is important for the utility. This variable is tightly related with the ones aforementioned before. The type of customer can help to improve the detection of incidents and the prediction of consumption. Moreover, it will allow targeted marketing campaigns for each type of customer. For example, some types of customers can be: "Customers out of home in summer", "Family with children", "Offices", "Commerce", "Hostelry".

Nowadays, electricity, water and gas readings can be done every few minutes. This fact, together with the fact of having high number of customers (which can usually be more than tens of thousands clients), makes very huge the volume of the data generated per day. Each reading is associated to a specific smart meter. This smart meter has associated a geographic location and some billing data. The billing data belong to a physical person or a company.

Our system is based on inductive inference methods that are able to anticipate the future based on past observed data. Our machine learning employs statistical techniques with the goal of enabling machines to understand the data set.

Phase 1: Unsupervised Clustering:

There are many types of customers, and each one follows different consumption patterns. However, this information is not directly known by the utility. To be able to characterize the type of customer and generalize its consumption, we have decided to include an unsupervised clustering phase. This allows us to assign each smart meter to a cluster with a differentiated consumption pattern.

Being unsupervised, the clusters are hidden. When more data is available, the assignation to a cluster can change, so this phase is recalculated periodically. The technique used in this phase is the k-means algorithm, which uses the consumption values (according to the hour of the day, day of the week, consumption in holidays, etc.), the maximum consumption contracted and its proximity to other smart meters of the same type.

Phase 2: Models Interference:

We have inferred three models following the three objectives set at the beginning of this section. The first model is able to extrapolate the future consumption of each meter at short and medium term. It is based on a statistical extrapolation model that uses as main training data, the historical of the consumption of the meter and the type of meter assigned in the clustering phase. This model is trained to predict the consumption of each meter in the next hour and in the next 24 hours.

The second model is able to activate certain alarms when an incident occurs. It is based on perceptron type multilayer neural networks. A different network is trained for each meter type obtained in the clustering phase. During training, the hourly consumption observed in the last 12 hours is used as input. Moreover, it is added the day of week, month of the year and the average consumption of the last 3 days. To train the exit, the event log is used. This log includes the incidents reported by the users or detected by the operators. The types of incidents collected are "small leak" (i.e. Flush with losses), "pipeline break", and "fraud indicators" (i.e. Consumption zero). The incident detection phase runs several times a day for each counter. It consists of introducing the appropriate entries in a neural network according to the type of meter and check whether any type of incident is activated.

The third model is a supervised clustering tool that allows classifying customers according to their consumption pattern. The main factor for differentiation are the times of day and the day of the week in which consumption occurs (for example, an office has very bounded consumption hours and zero consumption at weekends); consumption depending on the months of the year (for example, allow us to detect if it is a holiday day). Finally, the total amount of consumption (it would allow to differentiate between a single inhabitant or a large family). The techniques used in this stage are very similar to those used in the previous phase. The difference is that now the output is not a set of neural networks, but the classification obtained for each by the meters. The proposed big data architecture is shown in Figure 5.

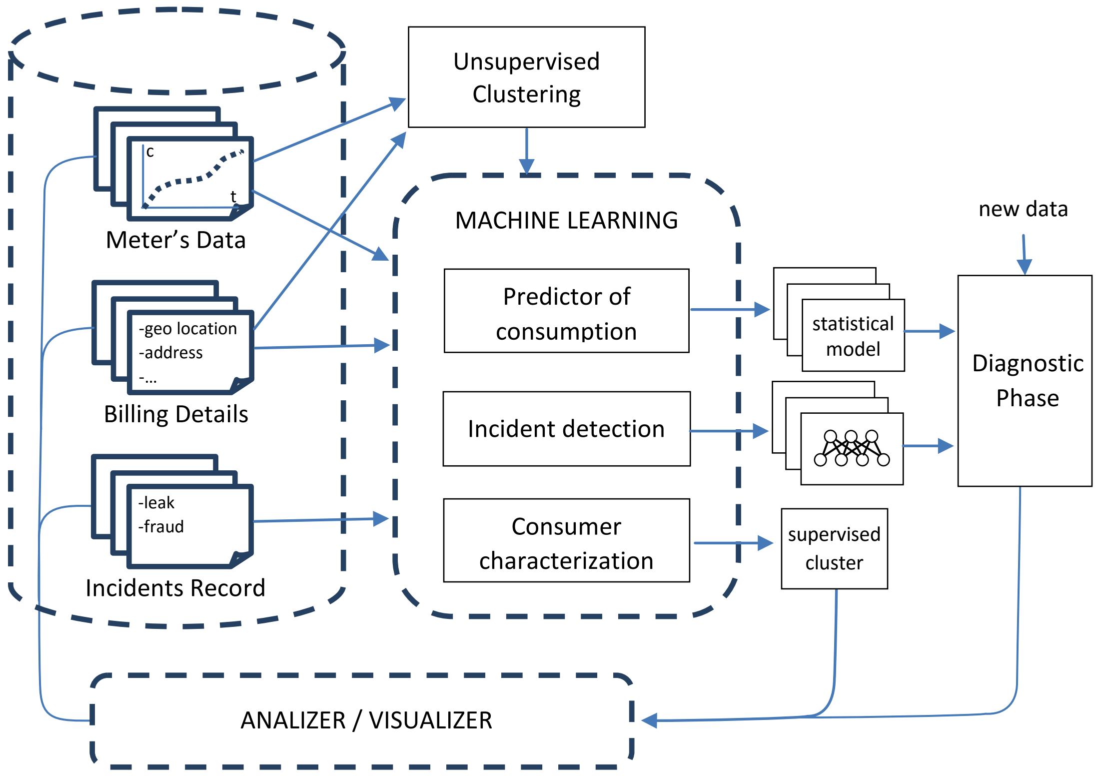

Figure 5. Proposed Big Data architecture

5. EXPERIMENTAL RESULTS

Consumption patterns can be created with the data received from the smart meters. Different consumption patterns can be obtained from different users, companies and even geographical areas, etc. With these patterns the utilities are able to carry out electricity, water or gas management studies. E.g., thanks to these studies, the electricity utilities can adjust the maximum generation to the power consumption by predicting the power demand. These patterns can be used to create user profiles like the amount of time at home, how much certain devices are used, etc. Moreover, utilities would be able to detect water or gas leaks by means of the information received from the smart meters. Utilities are able to identify consumption patterns related to leaks because they are able to identify and control the amount of lost water and gas.

The resulting casuistry from the information obtained with the smart meters offers the utility to classify customer profiles and customer habits. On one hand, this information allows obtaining consumption patterns that identify a type of customer that could be: a business, a home, a rural house, etc. On the other hand, the provider is able to predict the types of behaviour such as: peak consumption, habitability, etc.

Figure 6 shows several real examples of cases, In Figure 6a we find a one litre consumption peak of water during the day. This consumption pattern corresponds to a leak which could be a cistern leak. Figure 6b shows the power consumption on Saturdays, Sundays and holidays. As we can see, with this information the utility can carry out a prediction of the power consumption during these days. Figure 6c shows that a high consumption is detected at certain times of the day, from 6 to 9 am. This consumption pattern could belong to an irrigation area, where farmers often use these hours of the day to perform these tasks. In Figure 6d, there is continuous power consumption all year except during the summer months. With this information, the provider is able to detect that during the summer the customer is not living in that house.

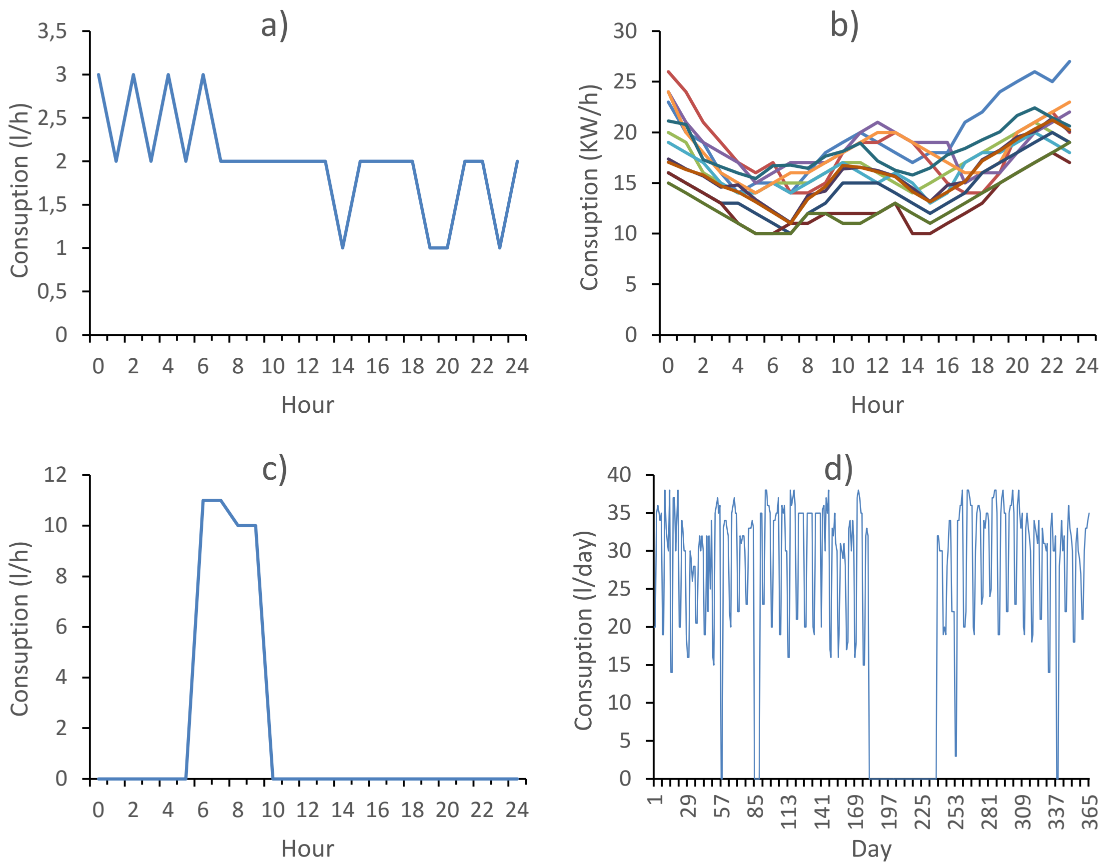

Figure 6.- Different consumption patterns

5.1. Results from data treatment

There are a number of advantages and benefits related to smart meters. To address the benefits derived from the installation of smart meters we must differentiate between the benefits for the utilities and the benefits for the customers.

The main benefits for the utilities are:

- Staff savings due to not having to physically go to read the meters.
- An increase of the reliability and quality of power, water and gas supply. When there is a fault, the system can detect and isolate the problem, and it contributes to a quick and strategic solution. So, it permits the detection and reparation of leaks that would damage the customer allowing more consumption efficiency.
- Contributes to maintain the environmental sustainability, and reduces the waste of energy, water and gas.
- It allows carrying out a forecast of consumption. This will help in improving efficiency in the distribution of electricity, water and gas flows, and flexibility in managing peak demand, resulting in reduced requirements for new generation facilities.
- It allows the detection of counterfeiting or tampering.
- The intelligent consumption analysis allows the providers to identify and solve any technical problems that may occur more quickly.

The main benefits for the consumers are:

- Consumption efficiency and leak detection (electricity, water or gas) at home with a consequent reduction in billing.
- The customers have the information and tools necessary to make decisions about their consumption. The customers can see how much and when they consume, in real-time, and save money by choosing the best time for electricity, water and gas consumption.
- Detection of electricity and water theft.

The robbery of electricity, water and gas mainly to the utilities, causes the increase of price to all consumers. It is also an issue that can affect people's safety, both the thieves and the customers, because the thief does not take security measures during the robbery and the damage that may affect the safety of the building and consequently the building users. Utilities can use the information gathered from the smart meters to detect frauds. For this, the consumption patterns are extracted and associated with customer profiles. Thus, personal consumption habits are obtained. When the customer habits change, an anomaly is detected. This could be related to a fraud.

But the fact of collecting these data allows the utility to take data from customer lives. Data can be analysed and subsequently, utility can establish patterns of user behaviour, which is not agreeable to many people. Most people do not like having their privacy invaded. So a customer should compare the balance between the benefits obtained and the loose of privacy. Our experience provides a real case in which a customer had a masked leak at home. According to the utility consumption pattern, during the summer the consumption should be zero, because the house was not inhabited, however, in its consumption data, there were a series of peaks of consumption that coincide with a possible leak, which then triggered an incidence.

6. Conclusion

In this paper we have proposed an integrated IoT architecture for electricity, water and gas smart metering, where the smart meters are “things” in Internet. We have reviewed the main features of the smart meters technology and the current communication protocols that can be used in our IoT architecture. Our proposal includes intelligent systems used in the Big Data to take decisions and provide information to the utility and customers. We have listed the benefits for both the utilities and customers and we have provided some real cases in order to show the power of the proposed system. Our future work is focused on increasing the data set of the smart meters to be able to work with more data taken at higher frequency and develop a robust protocol IoT protocol to support this amount of data.

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